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Jones et al.

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(54) **SURFACE MODIFIED UNIT CELL LATTICE STRUCTURES FOR OPTIMIZED SECURE FREEFORM FABRICATION**

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(51) **Int. Cl.**

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B29C 35/08	(2006.01)
G06F 17/50	(2006.01)

(52) **U.S. Cl.**
CPC ***G06F 17/50*** (2013.01)

(58) **Field of Classification Search**
USPC 264/497
See application file for complete search history.

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(57) **ABSTRACT**

Aspects of the present disclosure relate generally to preparing models of three-dimensional structures. In particular, a model of a three-dimensional structure constructed of porous geometries is prepared. A component file including a porous CAD volume having a predefined portion of a boundary. A space including the porous CAD volume is populated with unit cells overlapping the predefined portion of the boundary. The unit cells are populated with porous geometries having a plurality of struts having nodes on each end. At least a first strut overlaps the predefined portion of the boundary and has a length, a first node outside the porous CAD volume, and a second node inside the porous CAD volume. All struts entirely outside the porous CAD volume are removed. After removal of the struts entirely outside the porous CAD volume, each of the remaining struts is connected to a node at each end thereof.

20 Claims, 18 Drawing Sheets

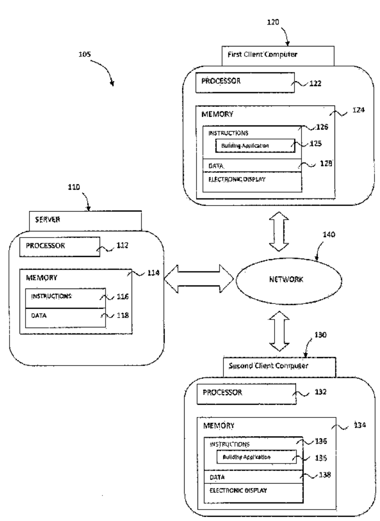

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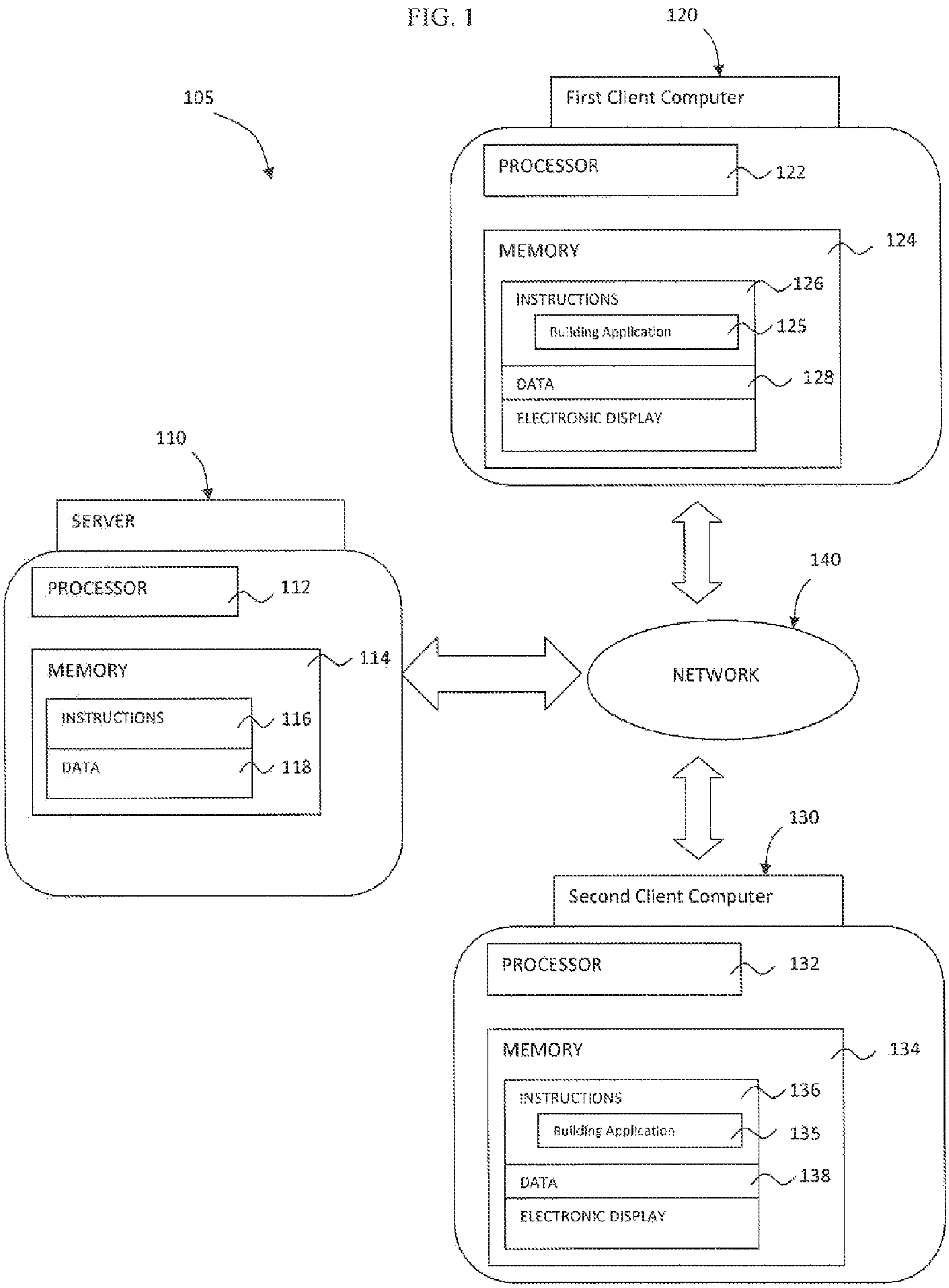
FIG. 1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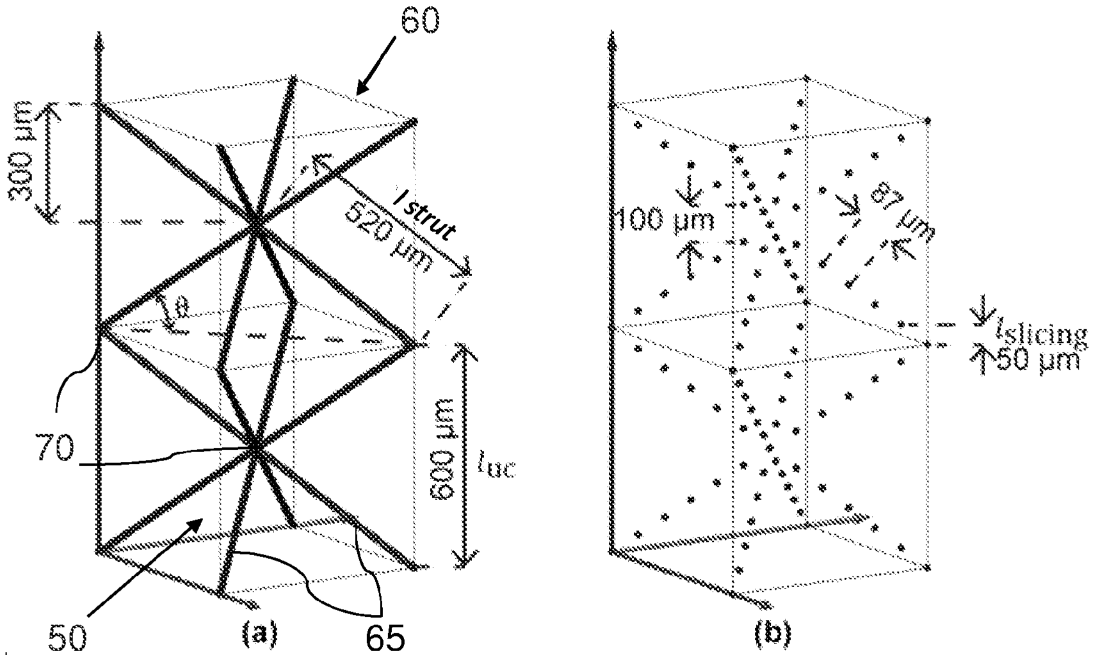
ELECTRONIC DISPLAY



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520 μm
θ
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(a)
65
100 μm
87 μm
$l_{slicing}$
50 μm
(b)

FIG. 2

FIG. 3

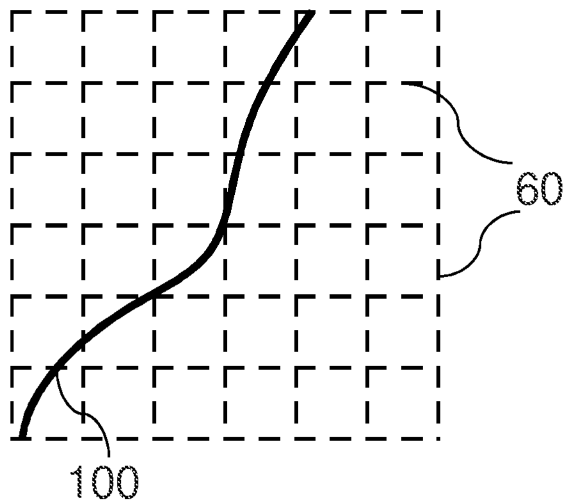


FIG. 4

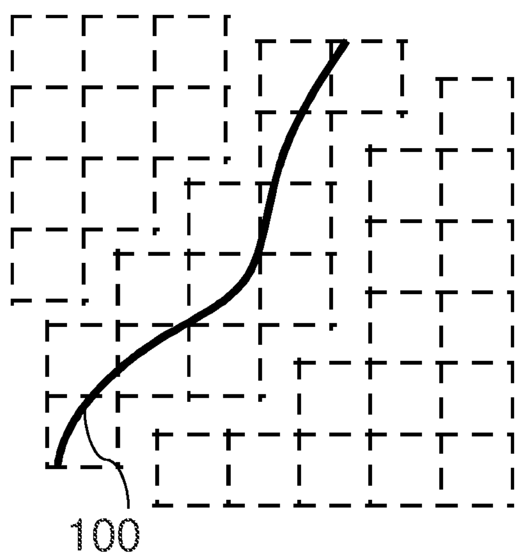


FIG. 5

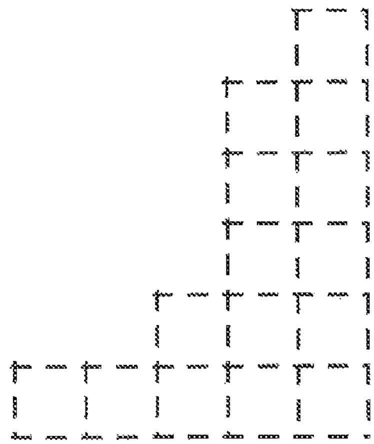


FIG. 6

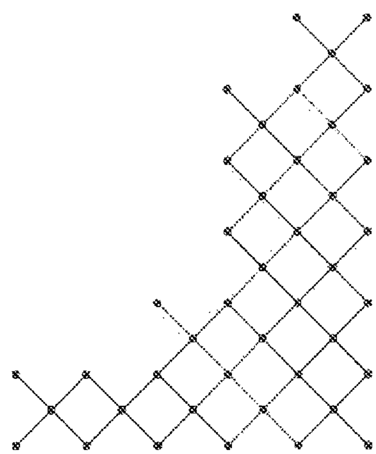
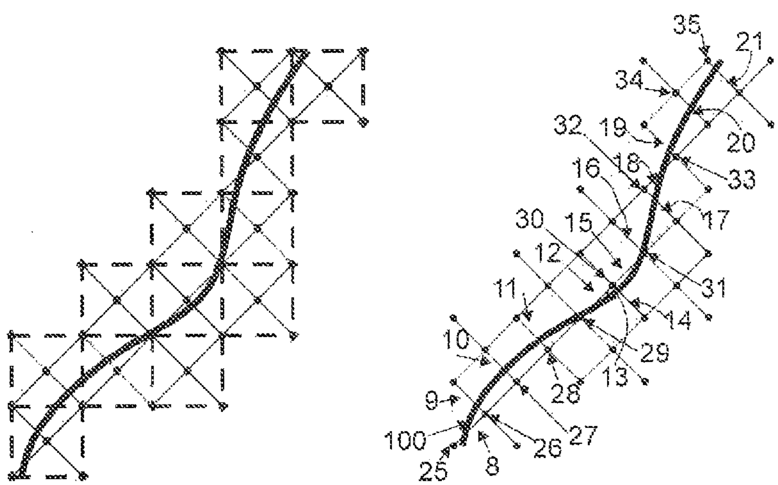


FIG. 7



(a) (b)

FIG. 8

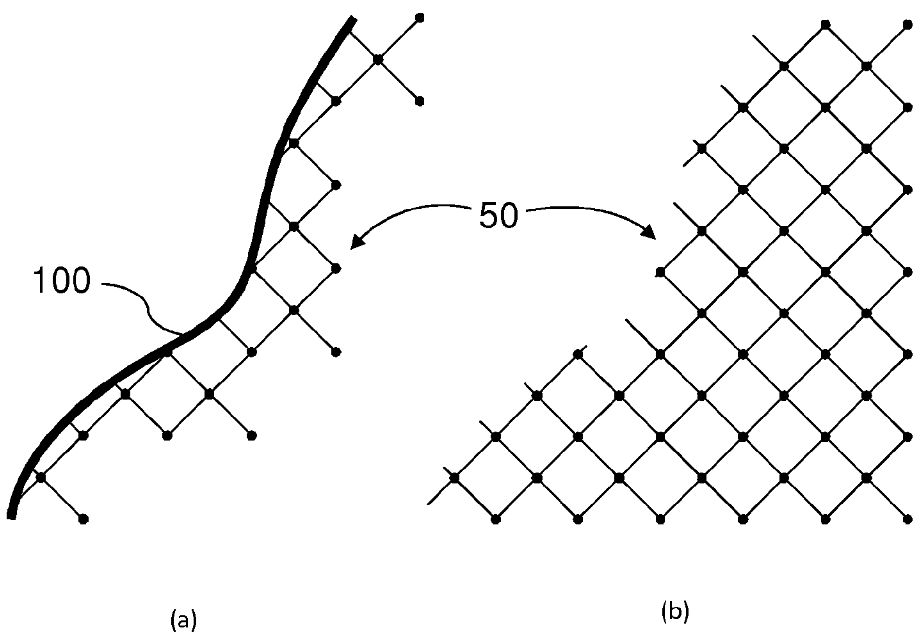


FIG. 9

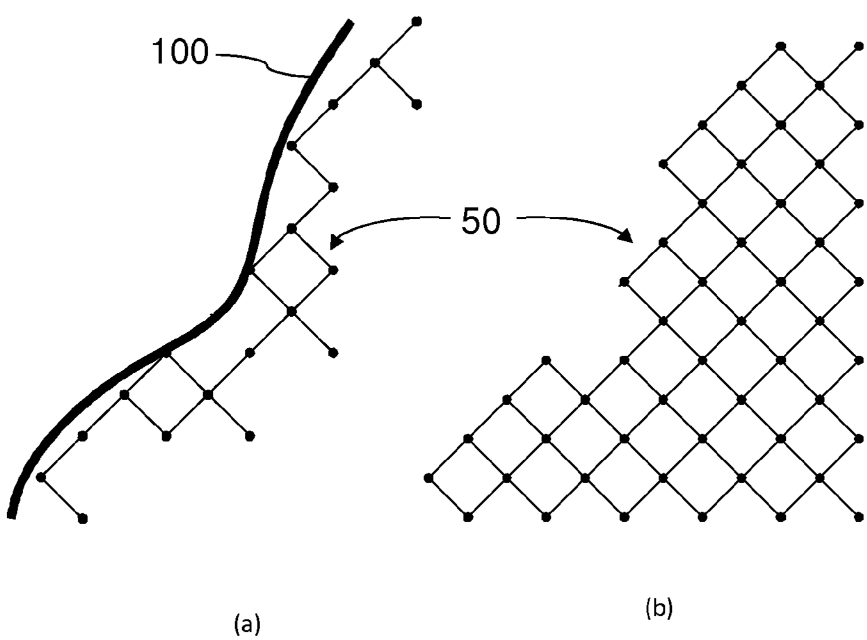


FIG. 10

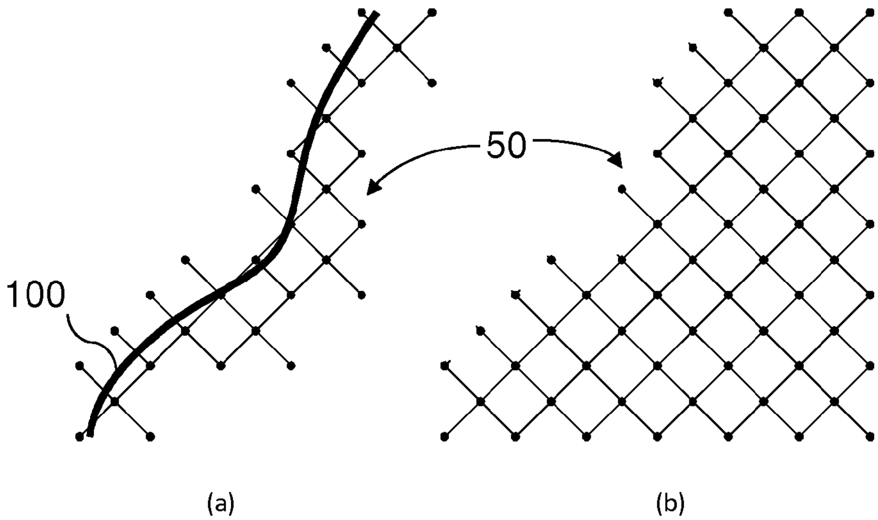


FIG. 11

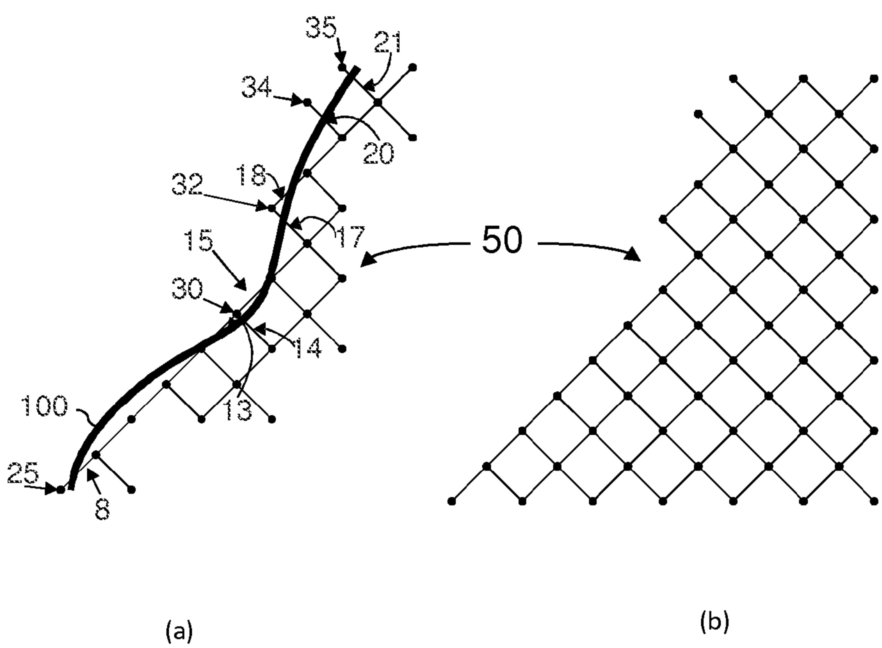
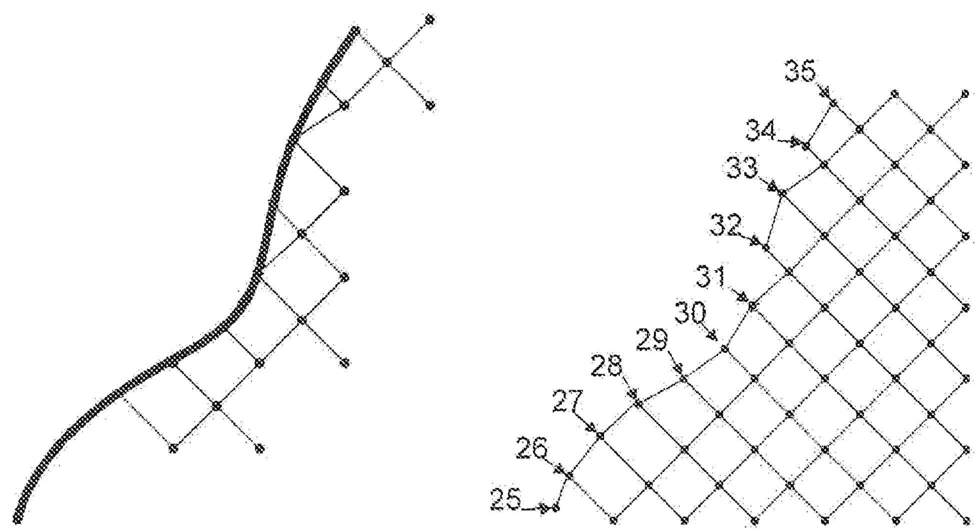
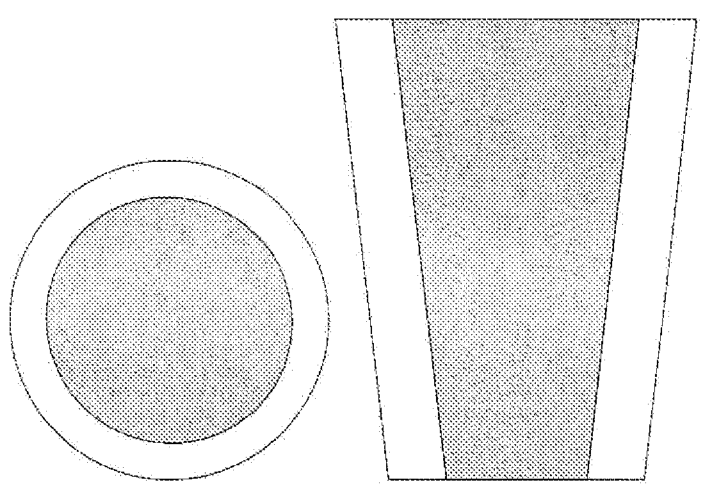


FIG. 12



(a) (b)

FIG. 13



(a) (b)

FIG. 14

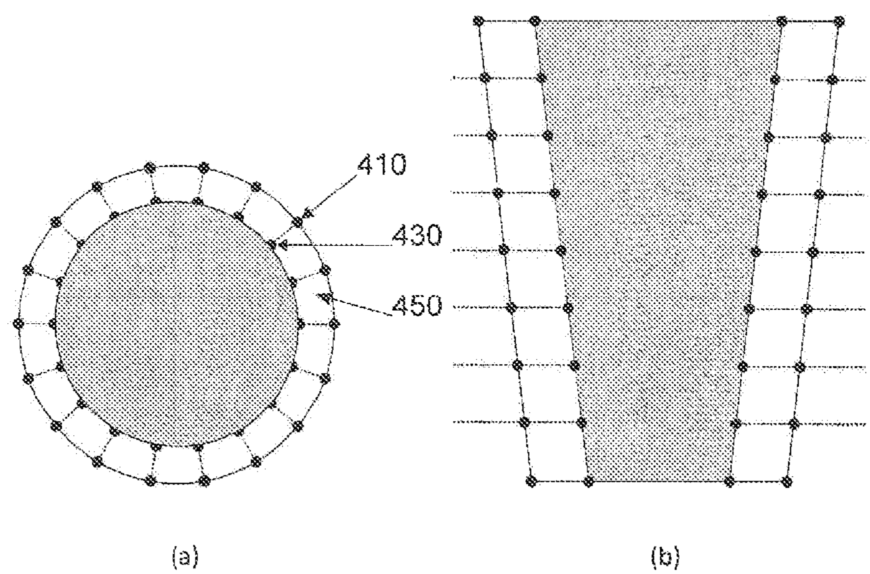


FIG. 15

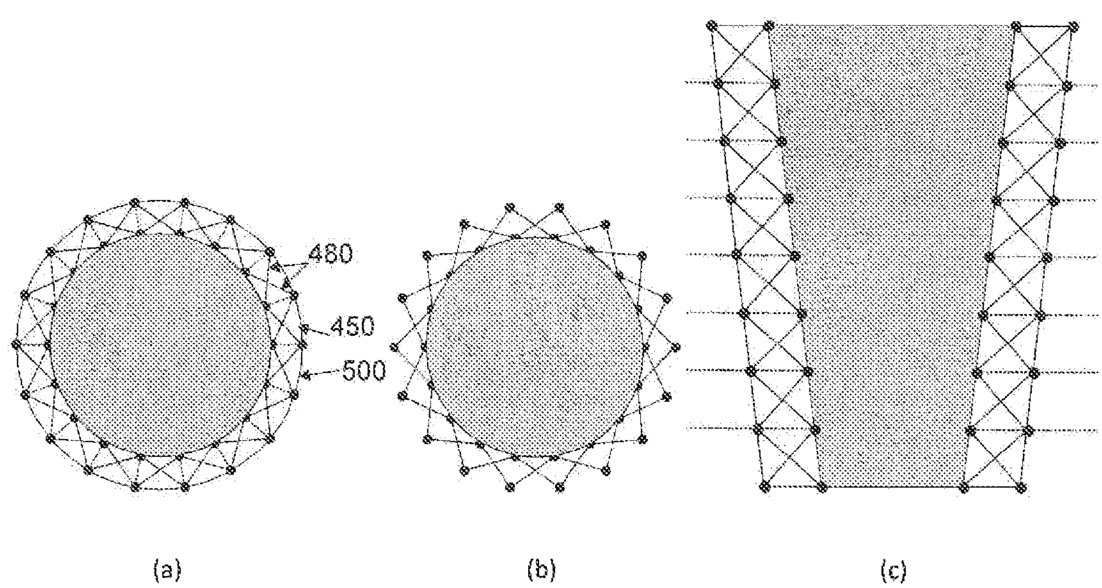


FIG. 16

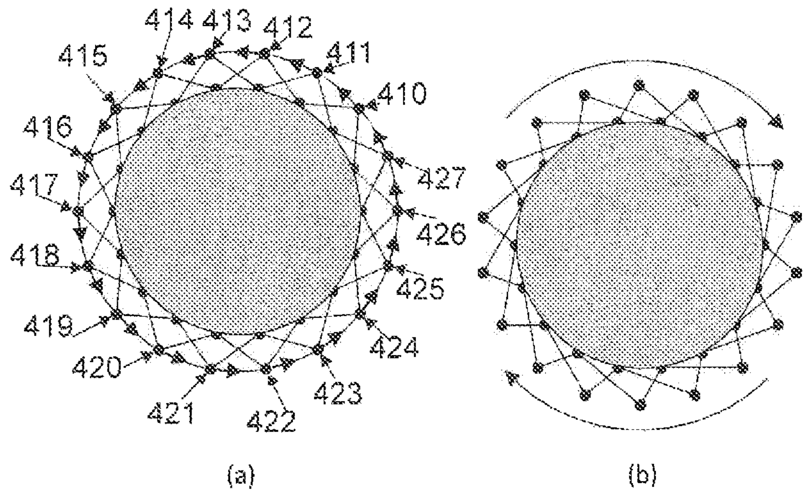


FIG. 17

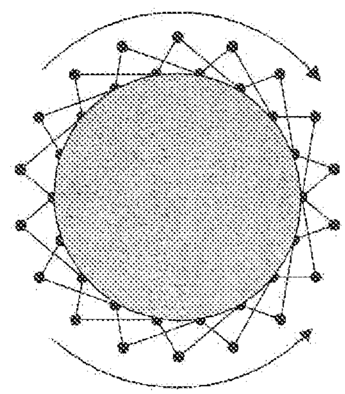


FIG. 18

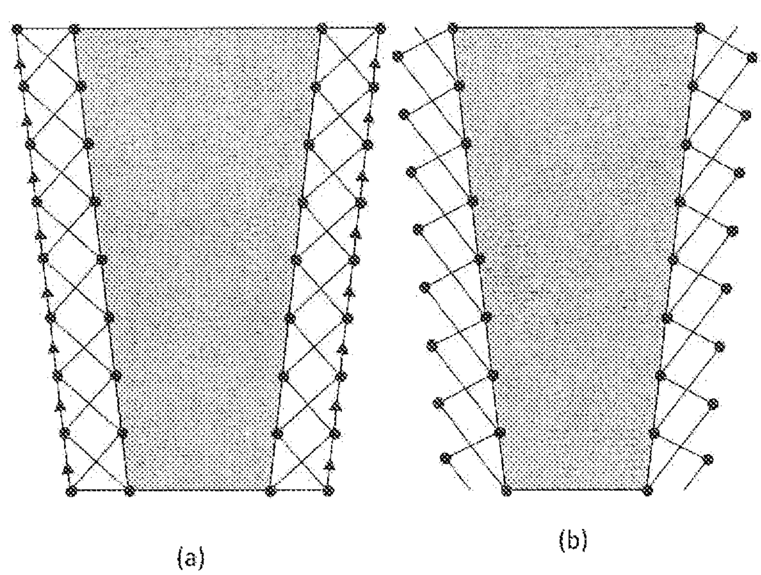
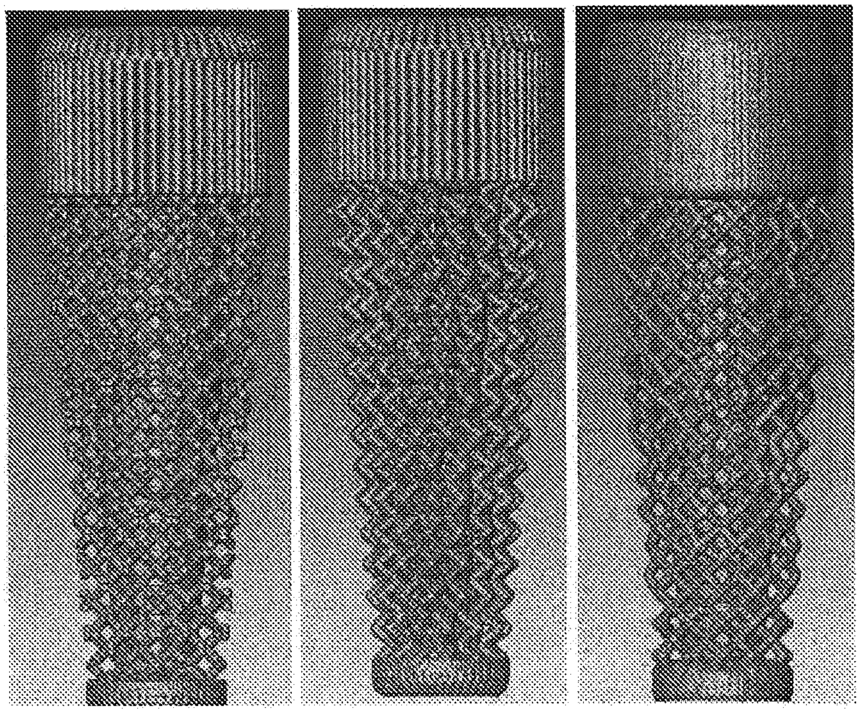
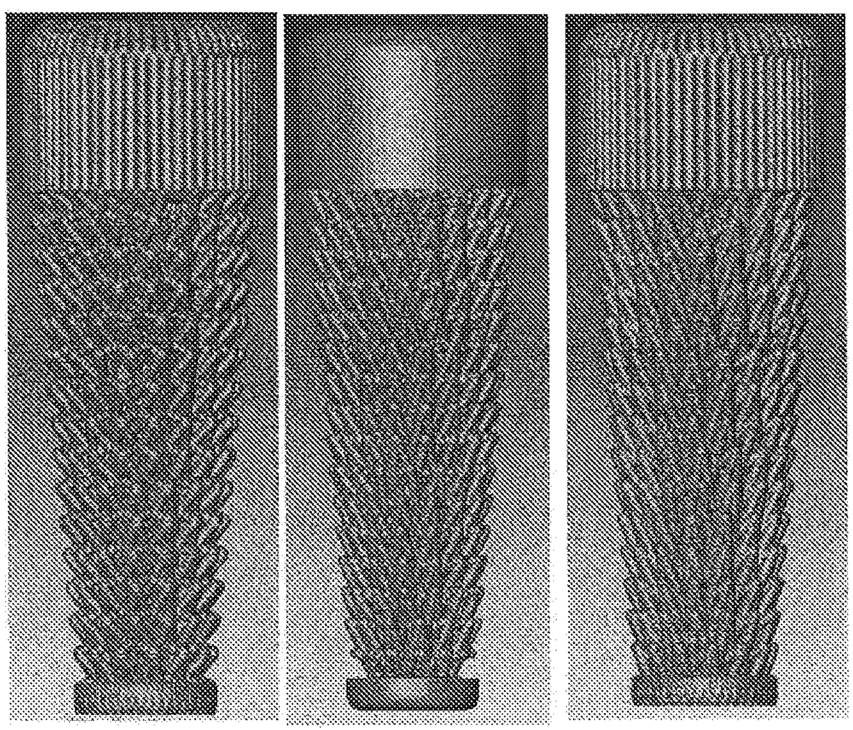


FIG. 19



(a) (b) (c)

FIG. 20



(a) (b) (c)

FIG. 21

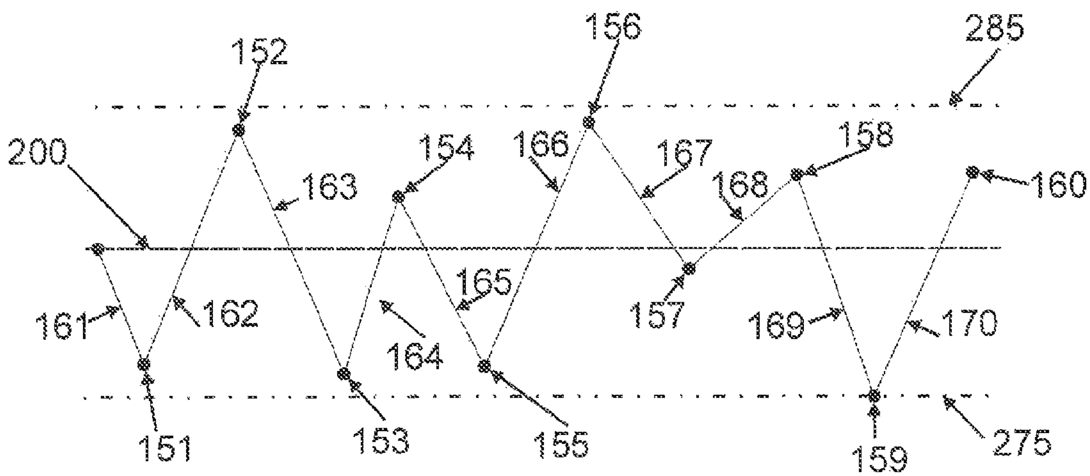

152
156
285
200
154
166
167
158
163
168
160
165
161
162
157
169
170
164
151
153
155
159
275

FIG. 22

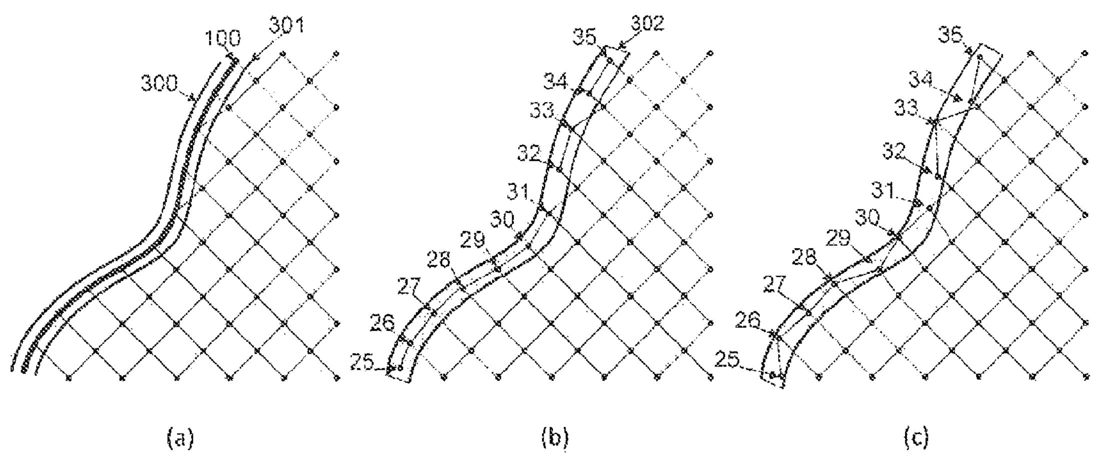
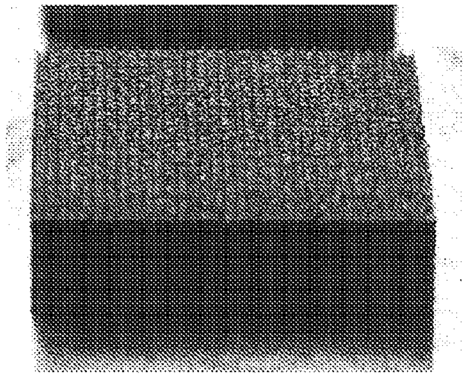
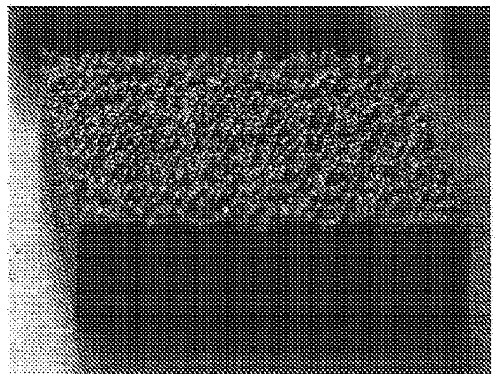

100
301
300
35
302
34
33
32
31
30
29
28
27
26
25
(a)
(b)
(c)

FIG. 23



(a)



(b)

FIG. 24

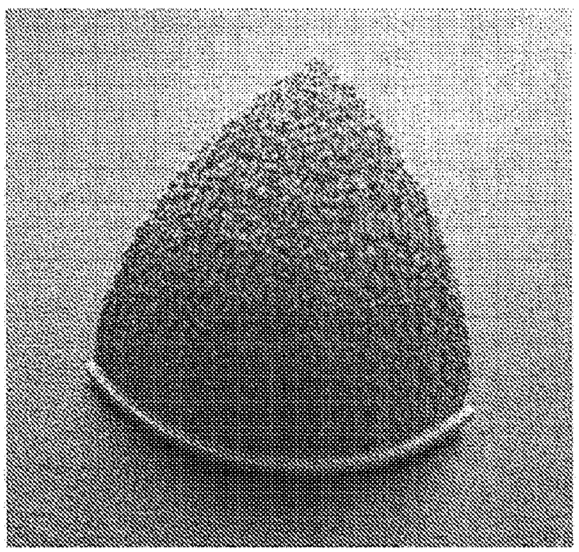
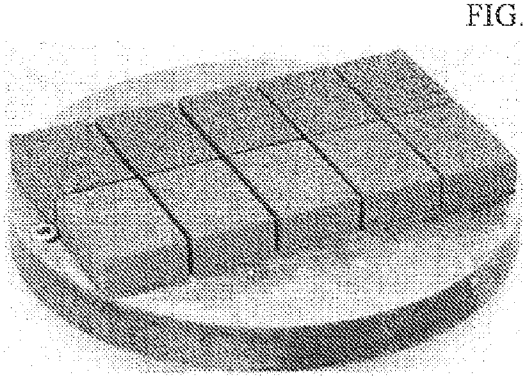
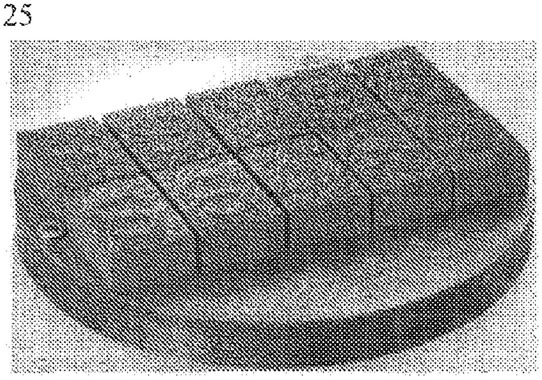


FIG. 25

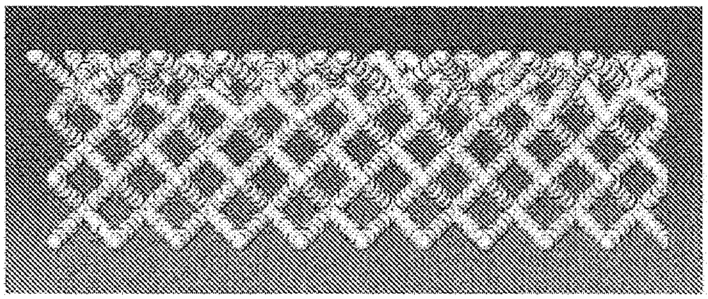


(a)

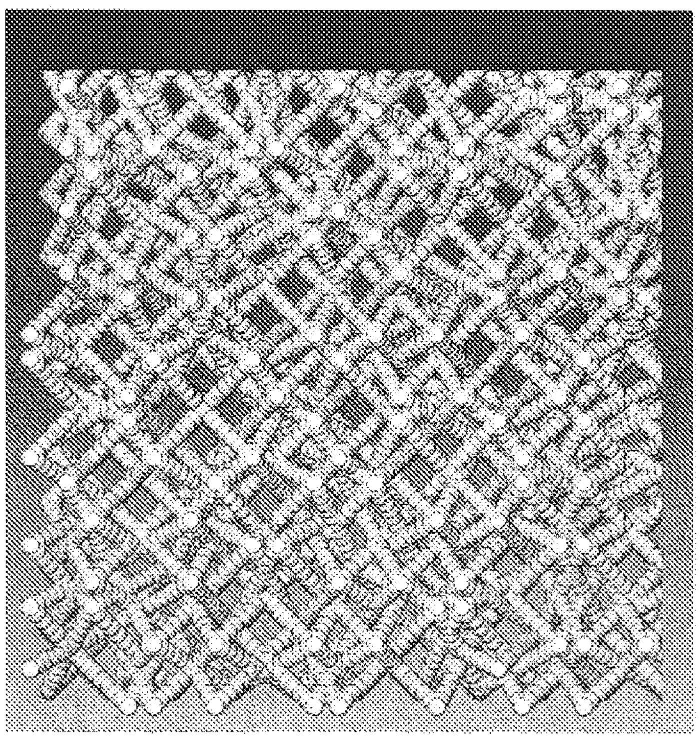


(b)

FIG. 26



(a)



(b)

FIG. 27

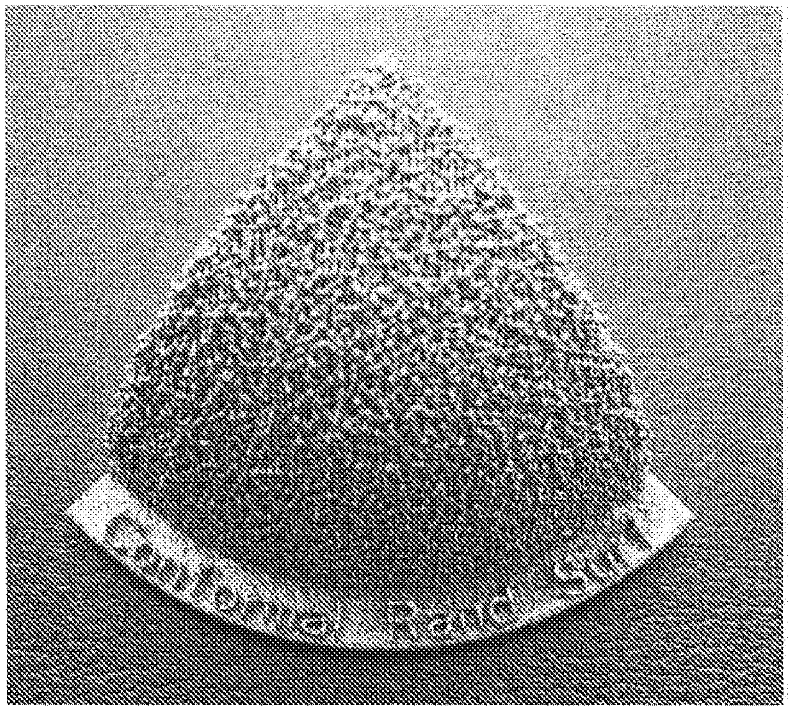
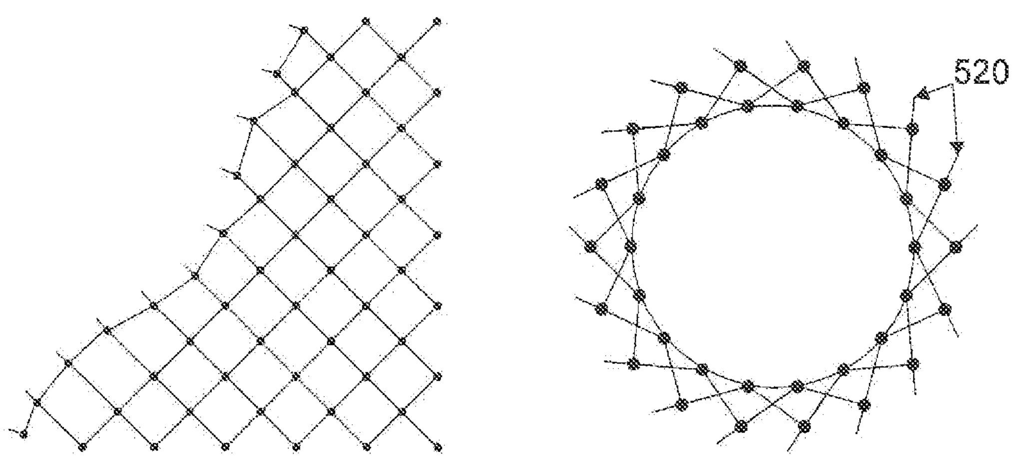


FIG. 28



(a) (b)

FIG. 29

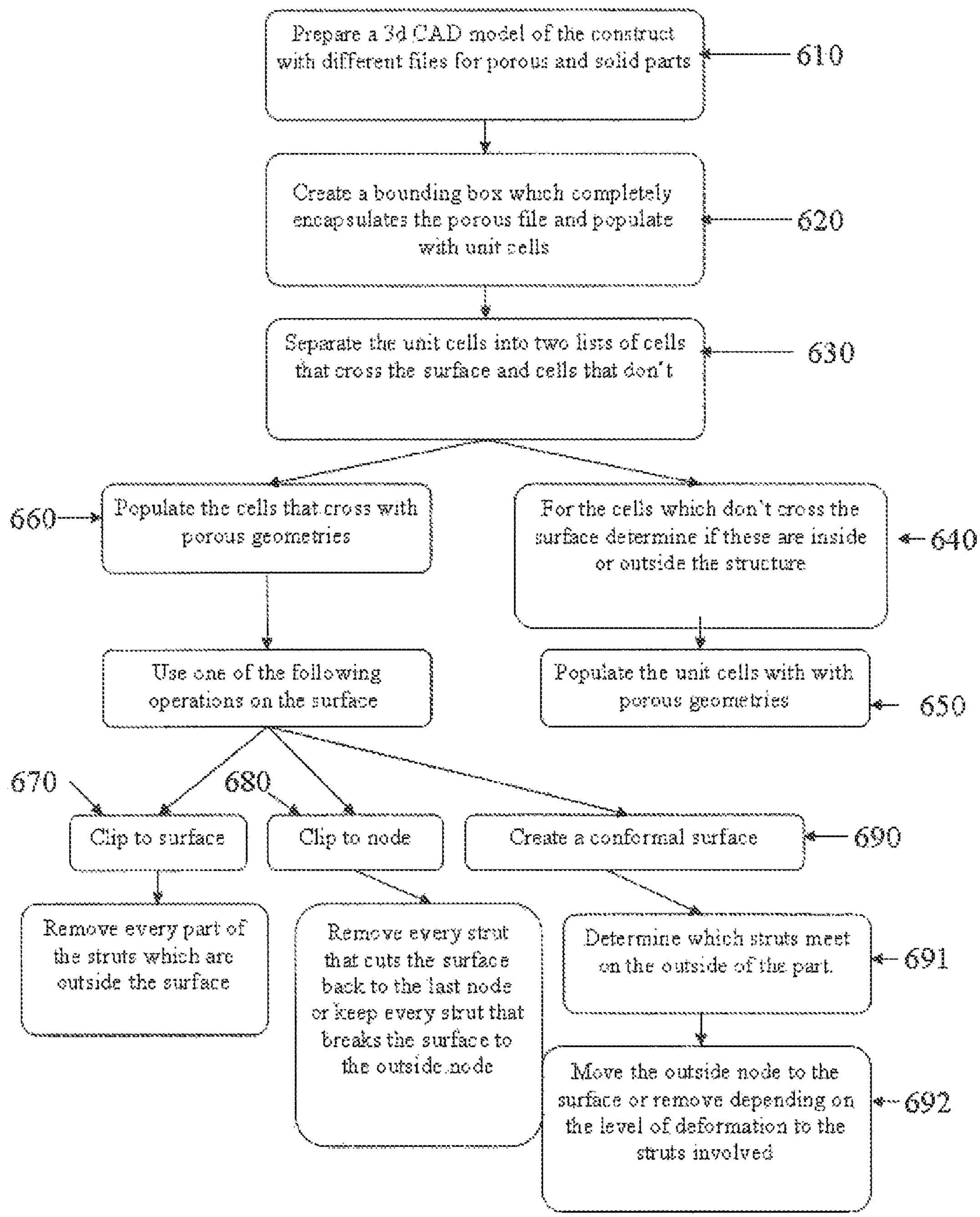

Prepare a 3d CAD model of the construct with different files for porous and solid parts
610
Create a bounding box which completely encapsulates the porous file and populate with unit cells
620
Separate the unit cells into two lists of cells that cross the surface and cells that don't
630
660
Populate the cells that cross with porous geometries
For the cells which don't cross the surface determine if these are inside or outside the structure
640
Use one of the following operations on the surface
Populate the unit cells with with porous geometries
650
670
680
Clip to surface
Clip to node
Create a conformal surface
690
Remove every part of the struts which are outside the surface
Remove every strut that cuts the surface back to the last node or keep every strut that breaks the surface to the outside node
Determine which struts meet on the outside of the part.
691
Move the outside node to the surface or remove depending on the level of deformation to the struts involved
692

FIG. 30

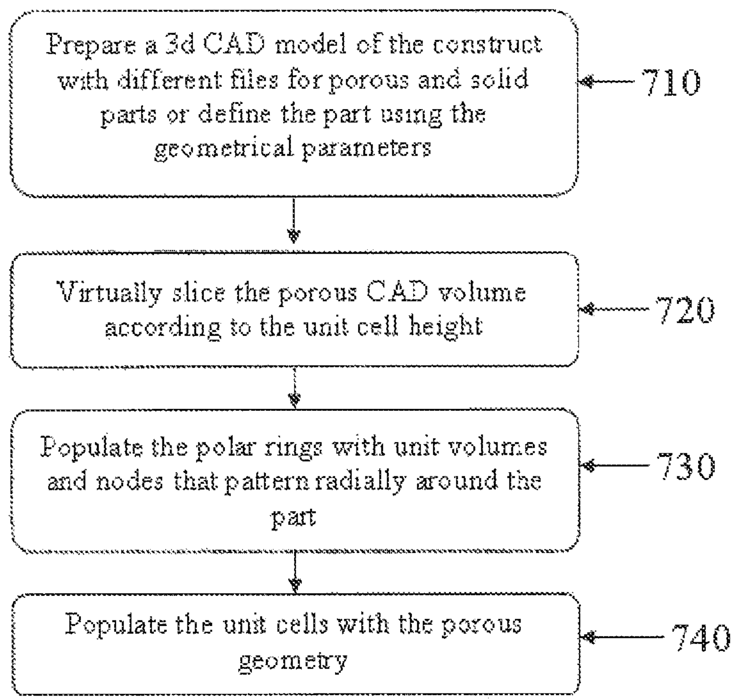

Prepare a 3d CAD model of the construct with different files for porous and solid parts or define the part using the geometrical parameters
710
Virtually slice the porous CAD volume according to the unit cell height
720
Populate the polar rings with unit volumes and nodes that pattern radially around the part
730
Populate the unit cells with the porous geometry
740

FIG. 31

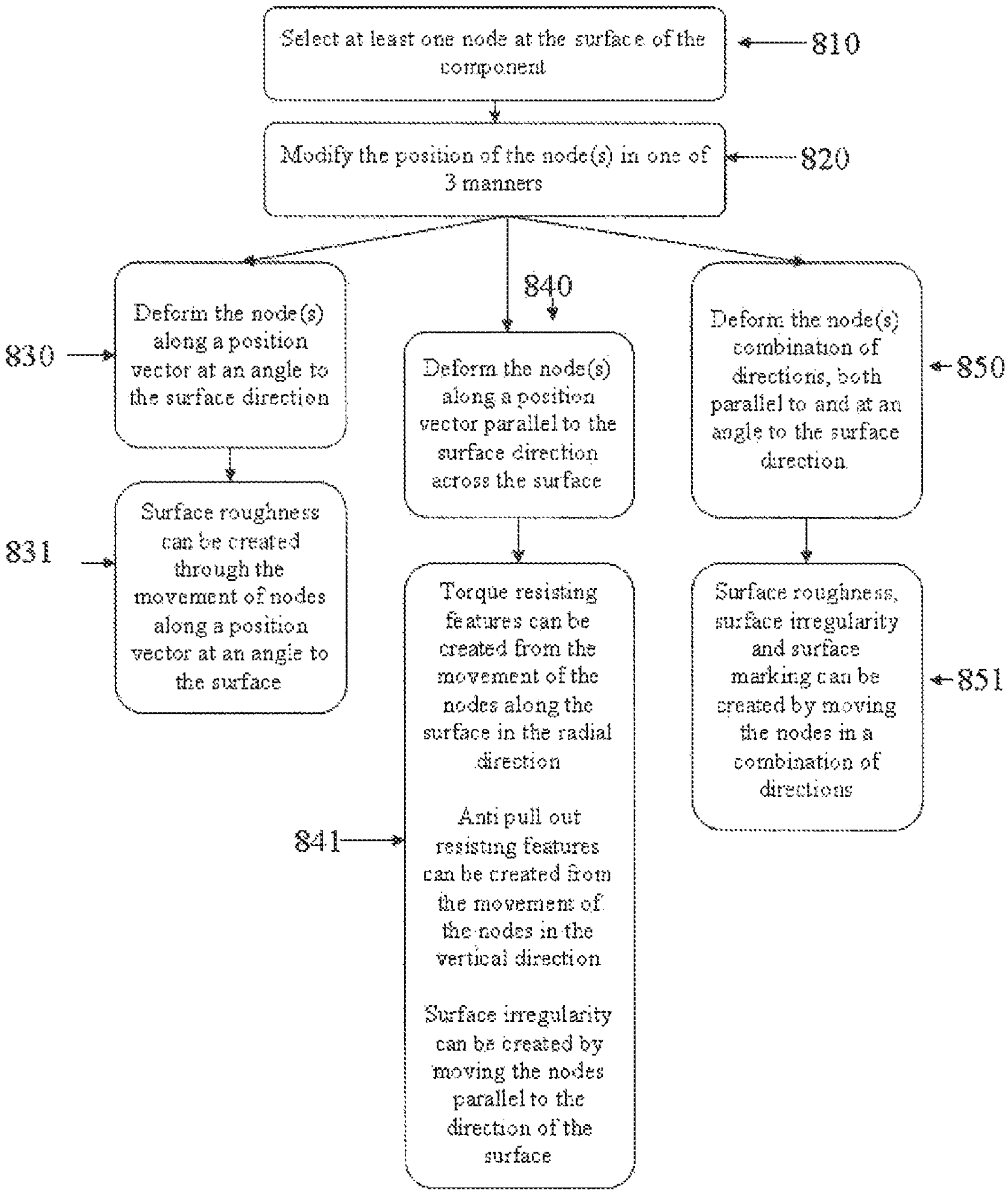
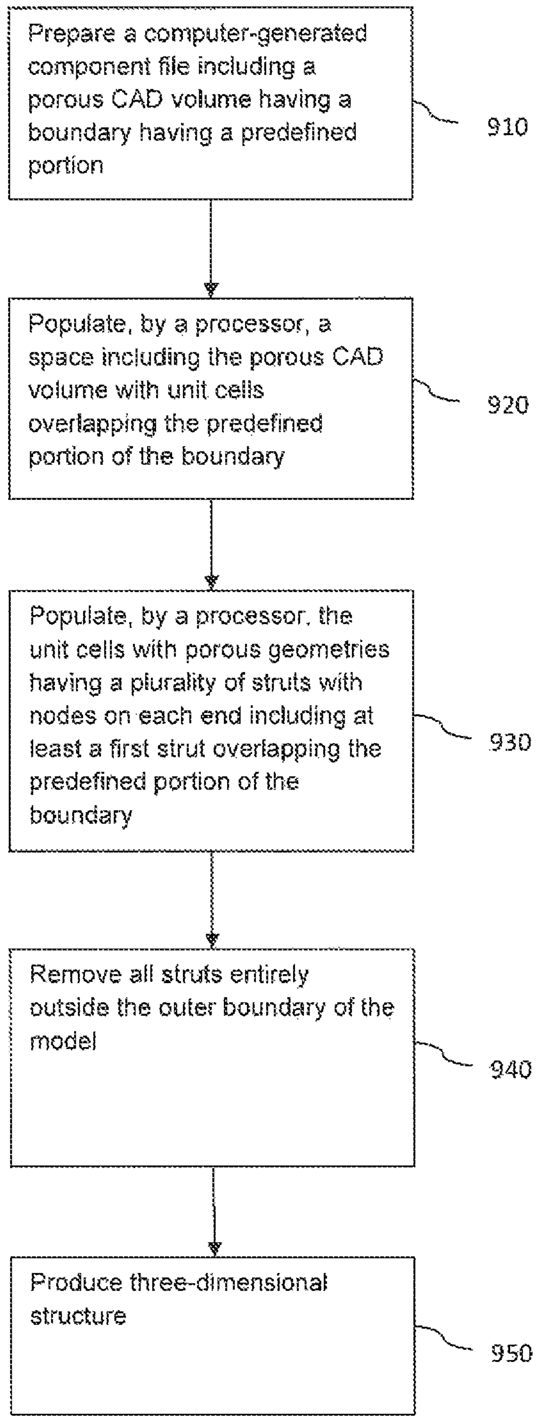

Select at least one node at the surface of the component
810
Modify the position of the node(s) in one of 3 manners
820
Deform the node(s) along a position vector at an angle to the surface direction
830
840
Deform the node(s) along a position vector parallel to the surface direction across the surface
Deform the node(s) combination of directions, both parallel to and at an angle to the surface direction
850
Surface roughness can be created through the movement of nodes along a position vector at an angle to the surface
831
Torque resisting features can be created from the movement of the nodes along the surface in the radial direction
Anti pull out resisting features can be created from the movement of the nodes in the vertical direction
Surface irregularity can be created by moving the nodes parallel to the direction of the surface
841
Surface roughness, surface irregularity and surface marking can be created by moving the nodes in a combination of directions
851

FIG. 32


Prepare a computer-generated component file including a porous CAD volume having a boundary having a predefined portion
910
Populate, by a processor, a space including the porous CAD volume with unit cells overlapping the predefined portion of the boundary
920
Populate, by a processor, the unit cells with porous geometries having a plurality of struts with nodes on each end including at least a first strut overlapping the predefined portion of the boundary
930
Remove all struts entirely outside the outer boundary of the model
940
Produce three-dimensional structure
950

SURFACE MODIFIED UNIT CELL LATTICE STRUCTURES FOR OPTIMIZED SECURE FREEFORM FABRICATION

FIELD OF THE INVENTION

The present invention relates generally to preparing computer-generated models of porous structures. In particular, the surfaces of computer-generated models of structures may be modified through movement and removal of struts and nodes of porous geometries near the surface to produce surfaces conforming to the surfaces of intended physical structures being modelled.

BACKGROUND OF THE INVENTION

The field of free-form fabrication has seen many important recent advances in the fabrication of articles directly from computer controlled databases. These advances, many of which are in the field of rapid prototyping of articles such as prototype parts and mold dies, have greatly reduced the time and expense required to fabricate articles, particularly in contrast to conventional machining processes in which a block of material, such as a metal, is machined according to engineering drawings.

One example of a modern rapid prototyping technology is a selective laser sintering process. According to this technology, articles are produced in layer-wise fashion from a laser-fusible powder that is dispensed one layer at a time. The powder is sintered, by the application of laser energy that is directed in raster-scan fashion to portions of the powder layer corresponding to a cross section of the article. After the sintering of the powder on one particular layer, an additional layer of powder is dispensed, and the process repeated, with sintering taking place between the current layer and the previously laid layers until the article is complete. Detailed descriptions of the selective laser sintering technology may be found in U.S. Pat. No. 4,863,538, U.S. Pat. No. 5,017,753, U.S. Pat. No. 5,076,869 and U.S. Pat. No. 4,944,817, the entire disclosures of which are incorporated by reference herein. Similarly, a detailed description of the use of selective laser melting technology may be found in U.S. patent application Ser. No. 10/704,270, filed on Nov. 7, 2003, now U.S. Pat. No. 7,537,664 ("the '664 patent"), the disclosure of which is incorporated by reference herein. The selective laser melting and sintering technologies have enabled the direct manufacture of solid or porous three-dimensional articles of high resolution and dimensional accuracy from a variety of materials including wax, metal powders with binders, polycarbonate, nylon, other plastics and composite materials, such as polymer-coated metals and ceramics.

The invention claimed in the '664 patent was the first of many inventions assigned to Howmedica Osteonics Corporation, who has been a pioneer in porous surface and porous structure formation, specifically for use in orthopedics. For instance, other applications in this area, such as U.S. patent application Ser. No. 11/027,421 filed on Dec. 30, 2004 ("the '421 Application"), and U.S. patent application Ser. No. 12/846,327 filed on Jul. 29, 2010 ("the '327 Application"), the entire disclosures of which are hereby incorporated by reference herein, have taught the generation of a population of porous geometry, a mathematical representation of the portion of geometry of the porous structure to be built within a region defined by predetermined unit cells or imaginary volumes that are organized to fill and form a predetermined build geometry, which may be used to produce a near net-shape of an intended porous tissue in-growth structure. The predetermined build geometry, or overall computer-aided design (CAD) geometry, may refer to the mathematical or pictorial representation (such as that on a computer display) of the extent or outer boundary of an intended physical structure to be manufactured. In the case of physical components that include both porous material and solid material, the build geometry may be an assembly of solid and porous CAD volumes that model the outer boundaries of the respective solid and porous materials intended to be manufactured. Furthermore, these applications teach the randomization of the position of interconnected nodes, or points of intersection between two struts or between a strut and a substrate, that define each of the porous geometries while maintaining the interconnectivity between the nodes. As previously taught, such randomization may accomplished by changing the coordinate positions of the nodes in the x, y, and z directions of a Cartesian coordinate system, to new positions based on a defined mathematical function. To achieve a required external shape for a device being created, these references have taught the truncation or removal of struts forming the unit cells at the outer surface. Such truncation helps to achieve the near-net shape of the intended structure, but truncated or clipped struts may, in some instances, create a situation where the porous geometries are un-supported by the underlying structures. These truncated struts may present a potential site for the generation of debris as protruding struts may fracture. Thus, a new method is needed to create build geometries having surfaces that are more robust and less likely to form debris.

SUMMARY OF THE INVENTION

In accordance with an embodiment of the invention, a process of preparing a computer generated model of a three dimensional structure constructed of porous geometries may include a step of preparing a computer-generated component file including a porous CAD volume having a boundary having a predefined portion. The process for preparing the model may include a step of populating, by a processor, a space. The space may include the porous CAD volume which may be populated by unit cells that overlap the predefined portion of the boundary. The process for preparing the model may include a step of populating, by a processor, the unit cells with porous geometries. The porous geometries may have a plurality of struts with nodes at each of the ends of the struts including a first strut overlapping the predefined portion of the boundary. The first strut may have a length, a first node outside the porous CAD volume, and a second node inside the porous CAD volume. The process for preparing the model may include a step of removing all struts entirely outside the porous CAD volume in which after the removal of the struts entirely outside the porous CAD volume, each of the remaining struts is connected to a node at each end of the remaining struts.

In accordance with a further embodiment of the invention, a process of preparing a computer generated model of a three dimensional structure constructed of porous geometries may include a step of preparing a computer-generated component file including a porous CAD volume having a boundary with a predefined portion. The process may include a step of populating, by a processor, a space. The space may include the porous CAD volume which may be populated by unit cells that overlap the predefined portion of the boundary. The process for preparing the model may include a step of populating, by a processor, the unit cells with porous geometries in which the porous geometries have a plurality of struts with nodes at each of the ends of the struts including a first strut that intersects the predefined portion of the boundary. The first strut may have a length and a first node at a first location that may be on the predefined outer boundary or outside the porous CAD volume. The process for preparing the model may include a step of removing all struts entirely outside the porous CAD volume. The process for preparing the model may include a step of moving the first node from the first location to a second location.

In accordance with a further embodiment of the invention a tangible computer-readable storage medium may have computer readable instructions of a program stored on the medium. The instructions, when executed by a processor, may cause the processor to perform a process of preparing a computer generated model of a three dimensional structure constructed of unit cells. The process of preparing the model may a step of preparing a computer-generated component file including a porous CAD volume having a boundary having a predefined portion. The process for preparing the model may include a step of populating, by a processor, a space. The space may include the porous CAD volume which may be populated by unit cells that overlap the predefined portion of the boundary. The process for preparing the model may include a step of populating, by a processor, the unit cells with porous geometries. The porous geometries may have a plurality of struts with nodes at each of the ends of the struts including a first strut overlapping the predefined portion of the boundary. The first strut may have a length, a first node outside the porous CAD volume, and a second node inside the porous CAD volume. The process for preparing the model may include a step of removing all struts entirely outside the porous CAD volume in which after the removal of the struts entirely outside the porous CAD volume, each of the remaining struts is connected to a node at each end of the remaining struts.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a functional diagram of a system in accordance with an exemplary embodiment of the present invention;

FIG. **2**(*a*) is a three-dimensional schematic representation of two unit cells and two porous geometries located therein;

FIG. **2**(*b*) is a three-dimensional schematic representation of a spatial arrangement of melt spots that may be used to create the porous geometries of FIG. **2***a;*

FIG. **3** illustrates a two-dimensional representation of a bounding box containing unit cells in accordance with an embodiment of the invention;

FIG. **4** illustrates the unit cells of FIG. **3***separated* into those that intersect a boundary of a porous CAD volume and those that do not intersect the porous CAD volume;

FIG. **5** shows the complete unit cells lying within the boundary of the porous CAD volume that are retained as shown in FIG. **4**;

FIG. **6** illustrates a wireframe of porous geometries created within the retained unit cells shown in FIG. **5**;

FIG. **7**(*a*) illustrates a wireframe of porous geometries created within the unit cells that intersect the boundary of the porous CAD volume shown in FIG. **4**;

FIG. **7**(*b*) illustrates the nodes of the porous geometries within the unit cells of FIG. **7**(*a*).

FIGS. **8**(*a*) and (*b*) illustrate the wireframe of the porous geometries of FIG. **7** after clipping struts of the porous geometries at their intersections with the boundary of the porous CAD volume;

FIGS. **9**(*a*) and (*b*) illustrate the wireframe of the porous geometries of FIG. **7** after clipping the full lengths of struts that overlap the boundary of the porous CAD volume;

FIGS. **10**(*a*) and (*b*) illustrate the wireframe of the porous geometries of FIG. **7** after clipping the full lengths of struts that lie entirely outside the boundary of the porous CAD volume;

FIGS. **11**(*a*) and (*b*) illustrate the wireframe of the porous geometries of FIG. **7** after clipping the full length of struts overlapping the boundary and having an inner node closest to the boundary to their respective inner nodes and the full length of struts lying entirely outside the boundary, while retaining the struts having the full length of struts overlapping the boundary and having an outer node closest to the boundary of the porous CAD volume;

FIGS. **12**(*a*) and (*b*) illustrate the wireframe of the porous geometries of FIG. **11** after repositioning of the nodes closest to the boundary to positions along the boundary of the porous CAD volume through conformal manipulation;

FIGS. **13**(*a*) and (*b*) show plan and side cross-sectional views, respectively, of a solid CAD volume surrounded by a boundary of a porous CAD volume of a tapered cylindrical geometry for use in accordance with an embodiment of the invention;

FIGS. **14**(*a*) and (*b*) show plan and side cross-sectional views, respectively, of the tapered cylindrical geometry of FIG. **13**, wherein nodes are populated at corners of unit cells within slices of the porous CAD volume through the use of polar coordinates;

FIGS. **15**(*a*)-(*c*) show a plan view including unit cells, a plan view without unit cells, and a side cross-sectional view, respectively, of the tapered cylindrical geometry of FIG. **14**, wherein struts connecting the nodes have been generated in a conformal manner;

FIGS. **16**(*a*) and (*b*) illustrate plan cross-sectional views of the tapered cylindrical geometry of FIG. **15**, before and after, respectively, repositioning of the nodes circumferentially about the cylindrical geometry at a boundary thereof in the same direction to create a structure with torque resistant properties.

FIG. **17** illustrates a plan cross-sectional view of the tapered cylindrical geometry of FIG. **16**(*a*) after repositioning of the nodes circumferentially about the cylindrical geometry at the boundary thereof in opposite directions on opposite portions to create a structure with torque resistant properties;

FIGS. **18**(*a*) and (*b*) illustrate side cross-sectional views of the tapered cylindrical geometry of FIG. **15**, before and after, respectively, repositioning of the nodes longitudinally along the cylindrical geometry at the boundary thereof to create structures with anti back-out properties;

FIGS. **19**(*a*)-(*c*) illustrate computer-generated models of cylindrical structures created by (a) clipping struts, positioned using Cartesian coordinates, at a boundary of a porous CAD volume, (b) positioning nodes based on polar coordinates, and (c) positioning nodes using Cartesian coordinates including repositioning of the nodes closest to the boundary to positions along the boundary of the porous CAD volume through conformal manipulation;

FIGS. **20**(*a*)-(*c*) illustrate computer-generated models of structures created by positioning struts based on polar coordinates and then displacing nodes by varying amounts to create anti-back out functions;

FIG. **21** is a schematic of a surface produced by manipulating nodes in accordance with an embodiment of the invention to create a desired surface roughness;

FIGS. **22**(*a*)-(*c*) illustrate a process of roughening a predetermined surface by moving nodes within a defined region along the surface in accordance with an embodiment of the invention;

FIGS. **23**(*a*) and (*b*) show coupons having surfaces prepared by (a) applying and (b) not applying a predetermined surface roughness thereto in accordance with an embodiment of the present invention;

FIG. **24** shows a curved surface prepared by applying a predetermined surface roughness thereto in accordance with an embodiment of the present invention;

FIGS. **25**(*a*) and (*b*) show examples of flat surfaces prepared by applying a predetermined surface roughness thereto to create surface labelling in accordance with an embodiment of the invention;

FIGS. **26**(*a*) and (*b*) illustrate side elevation and plan views, respectively, of a model of a flat surface having surface node deformation to create irregularity in a specific area of a regular structure in accordance with an embodiment of the present invention;

FIG. **27** shows an example of a curved surface having surface node deformation to create irregularity in a specific area of a regular structure in accordance with an embodiment of the invention;

FIGS. **28**(*a*) and (*b*) illustrate the wireframes of the porous geometries of FIGS. **12** and **15**, respectively, having portions of struts added to the surface nodes of the respective porous CAD volumes;

FIG. **29** is a process flow diagram in accordance with an embodiment of the invention;

FIG. **30** is another process flow diagram in accordance with an embodiment of the invention;

FIG. **31** is another process flow diagram in accordance with an embodiment of the invention.

FIG. **32** is another process flow diagram in accordance with an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

This invention relates generally to generating computer models of three-dimensional structures. These models may be used to prepare porous tissue in-growth structures in medical implants and prostheses. The models may include features corresponding to tangible structures having nodes along a predefined outer boundary.

FIG. **1** depicts a system **105** that may be used, among other functions, to generate, store and share three-dimensional models of structures. The system **105** may include at least one server computer **110**, a first client computer **120**, and in some instances, at least a second client computer **130**. These computers may send and receive information via a network **140**. For example, a first user may generate a model at the first client device **120**. The model may then be uploaded to the server **110** and distributed via the network **140** to the second client computer **130** for viewing and modification by at least a second user.

The network **140**, and intervening communication points, may comprise various configurations and protocols including the Internet, World Wide Web, intranets, virtual private networks, wide area networks, local networks, private networks using communication protocols proprietary to one or more companies, Ethernet, WiFi and HTTP, and various combinations of the foregoing. Such communication may be facilitated by any device capable of transmitting data to and from other computers, such as modems (e.g., dial-up, cable or fiber optic) and wireless interfaces. Although only a few devices are depicted in FIG. **1**, a typical system may include a large number of connected computers, with each different computer being at a different communication point of the network.

Each of computers **110**, **120**, and **130** may include a processor and memory. For example, server **110** may include memory **114** which stores information accessible by a processor **112**, computer **120** may include memory **124** which stores information accessible by a processor **122**, and computer **130** may include memory **134** which stores information accessible by a processor **132**.

The processors **112**, **122**, **132** may be any conventional processor, such as commercially available CPUs. Alternatively, the processors may be dedicated controllers such as an ASIC, FPGA, or other hardware-based processor. Although shown in FIG. **1** as being within the same block, the processor and memory may actually comprise multiple processors and memories that may or may not be stored within the same physical housing. For example, memories may be a hard drive or other storage media located in a server farm of a network data center. Accordingly, references to a processor, memory, or computer will be understood to include references to a collection of processors, memories, or computers that may or may not operate in parallel.

The memories may include a first part storing applications or instructions **116**, **126**, **136** that may be executed by the respective processor. The instructions **116**, **126**, **136** may be any set of instructions to be executed directly (such as machine code) or indirectly (such as scripts) by the processor. In that regard, the terms "applications," "instructions," "steps" and "programs" may be used interchangeably herein.

The memories may also include a second part storing data **118**, **128**, **138** that may be retrieved, stored or modified in accordance with the respective instructions. The memory may include any type capable of storing information accessible by the processor, such as a hard-drive, memory card, ROM, RAM, DVD, CD-ROM, write-capable, and read-only memories or various combinations of the foregoing, where the applications **116** and data **118** are stored on the same or different types of media.

In addition to a processor, memory and instructions, client computers **120**, **130**, **131**, **133** may have all of the components used in connection with a personal computer. For example, the client computers may include an electronic display **150**, **151** (e.g., a monitor having a screen, a touch-screen, a projector, a television, a computer printer or any other electrical device that is operable to display information), one or more user inputs **152**, **153** (e.g., a mouse, keyboard, touch screen and/or microphone), speakers **154**, **155**, and all of the components used for connecting these elements to one another.

Instructions **126**, **136** of the first and second client devices **120**, **130** may include building applications **125**, **135**. For example, the building applications may be used by a user to create three-dimensional structures, such as those described further herein. The building applications may be associated with a graphical user interface for displaying on a client device in order to allow the user to utilize the functions of the building applications.

A building application may be a computer-aided design (CAD) three-dimensional (3-D) modeling program or equivalent as known in the art. Available CAD programs capable of generating such a structure include Autodesk® AutoCAD®, Creo® by Parametric Technology Corporation (formerly Pro/Engineer), Siemens PLM Software NX™ (formerly Unigraphics), and CATIA® by Dassault Systèmes. Such structures may be those described in the '421 Application.

The data **118**, **128**, **138** need not be limited by any particular data structure. For example, the data may be stored in computer registers, in a relational database as a table having a plurality of different fields and records, or XML documents.

The data may also be formatted into any computer-readable format such as, but not limited to, binary values, ASCII or Unicode. Moreover, the data may comprise any information sufficient to identify the relevant information, such as numbers, descriptive text, proprietary codes, pointers, references to data stored in other memories (including other network locations) or information that is used by a function to calculate the relevant data. For example, the data **128** of the first client device **120** may include information used by the building application **125** to create three-dimensional models.

In addition to the operations described above and illustrated in the FIGs., various other operations will now be described. It should be understood that the following operations do not have to be performed in the precise order described below. Rather, various steps may be handled in a different order or simultaneously. Steps may also be omitted or added unless otherwise stated herein.

An overall three-dimensional representation of a component may first be generated by preparing a CAD model. This overall CAD model may comprise of one or more distinct CAD volumes that are intended to be manufactured as either solid or porous geometries.

Solid CAD volumes can be sliced into layers of a predetermined thickness ready for hatching, re-merging with the porous volume (post-lattice generation) and subsequent manufacture.

Porous CAD volumes (the basic principles of which are detailed in FIGS. **2**(*a*) and (*b*) can be processed using bespoke software. In this case the porous geometry is made up of a plurality of struts organized within tessellating unit cells **60**. Many designs of porous geometry are possible to impart various strength, surface, and/or other characteristics into the porous CAD volume. For example, these porous geometries can be used to control the shape, type, degree, density, and size of porosity within the structure. Such porous geometry designs can be dodecahedral, octahedral, tetrahedral (diamond), as well as many other various shapes. In comparison, dodecahedral porous geometries have a different mechanical performance than a tetrahedral structure. Besides these regular geometric shapes, the porous geometries of the present invention may be configured to have irregular shapes where various sides and dimensions have little if any repeating sequences. Porous geometries can even be configured into constructs that closely mimic the structure of trabecular bone. Porous geometries can be space filling, in which all the space within a three-dimensional object is filled with porous geometries but do not always fill the space of an object they are used to produce.

FIG. **3** shows in greater detail a portion of a model build structure **50**, generated through the use of an engineering design package such as that described previously herein.

The first step in creating a porous CAD volume is calculate a bounding box, i.e., a box whose x, y, and z dimensions correspond to, or are slightly larger than, a defined boundary of the porous CAD volume, which may be the entire boundary or a portion of a boundary as shown in FIG. **3**. This bounding box is then divided into a number of unit cells defined by x, y, and z dimensions. Calculations are then performed during an interrogation on each individual unit cell to ascertain if each cell is within, or intersects the boundary of the porous CAD volume, as illustrated by FIGS. **4** and **5**. If these conditions are satisfied for an individual cell, the cell is retained, whereas if they are not, the cell is discarded. Once all cells have been interrogated, porous geometry is populated within the cells that have been retained, as shown in FIGS. **6** and **7**).

Various building blocks make up a porous geometry. Referring again to FIGS. **2** and **3** each of the porous geometries are made up of struts **65**, or segments having a length. Nearly all of the struts **65** of the model build structure **50** meet at a node or intersection **70**. The position of the nodes may be identified within an array of the data of the processor according to Cartesian, polar coordinates, or other user-defined coordinates.

The porous CAD volume has a predefined boundary **100** that corresponds to the intended outer surface of the part being designed. A portion of the boundary **100** is illustrated in FIG. **7**. As shown, some of the unit cells **60** along the predefined boundary **100** have overlapping struts **8-21** that cross over the boundary **100**. The struts **8-21** have inner nodes **26-29**, **31**, and **33** within the boundary **100** of the porous CAD volume and outer nodes **25**, **30**, **32**, **34**, and **35** outside of the boundary **100**.

To produce a porous structure having struts that terminate along the boundary, the overlapping struts may be clipped such that any portion of the overlapping struts beyond the predefined boundary is removed. FIG. **8** depicts a model build structure **50** generated according to this clipping approach, in other words, after the overlapping struts **8-21** have been clipped. The overlapping struts **8-21** are now shorter. The ends of each of the overlapping struts **8-21** now lie along the predefined outer boundary **100** and none of the overlapping struts **8-21** extend past the boundary **100**.

In some cases this clipping approach may be appropriate. However, the struts that have been shortened may not be supported at their outer points as can be seen in the model of FIG. **19**(*a*), and as such they can act as cantilevers and may result in an increased risk of debris formation. In some instances (assuming a flat edge is present), the porous CAD volume may be modified so that the boundary lies along a whole number of unit cells. In this instance there is no need for the clipping operation. This mitigates the possibility of debris generation as the end of each strut is supported by at least one other strut, and is correspondingly less prone to failure.

FIG. **9** shows the model build structure **50** prepared by another approach where the full length of struts that overlap the surface of the porous CAD volume are removed to the inner node. Thus the overlapping struts **8-21** are removed. Preferably, removal of these struts leaves only the complete porous geometries **60**. However, this approach may leave the surface rough, uneven and nonconforming to the original porous CAD volume as some of the unit cells **60** do not reach the outer boundary **100**.

FIG. **10** shows the model build structure **50** prepared by another approach where the full length of struts that overlap the surface of the porous CAD volume are retained to their respective outer nodes. In this manner, the overlapping struts **8-21** remain beyond the boundary **100** of the porous CAD volume.

FIG. **11** shows the model build structure **50** prepared by yet a further approach where each of these struts **8-21** are either fully retained or fully removed, depending on the distance of their nodes from the boundary **100** of the porous CAD volume. In the example shown, each of the unit cells **60** outside the outer boundary **100** as well as the struts **9-12**, **16** and **19** are removed (or marked for removal). The struts selected for removal are those overlapping struts in which the node outside the boundary, i.e., the outer node, is further from the boundary than the corresponding node of the overlapping strut inside the boundary, i.e., the inner node. In contrast, the overlapping struts **8**, **13-15**, **17-18**, and **20-21** are not removed because their corresponding nodes **25**, **30**, **32**, **34**, and **35**, although outside the outer boundary **100** are closer to the boundary **100** than their corresponding inner nodes.

FIG. **12** shows the model build structure **50** prepared after clipping, followed by the repositioning of the remaining nodes **25-35**, closest to the boundary **100** of the porous CAD volume to coincide with the boundary **100**. In some embodiments, each of the nodes **25-35** closest to the boundary **100** may be repositioned to a location determined by a mathematical calculation based on the original position of each of these nodes, e.g., the distance from the boundary of each of these nodes, or the original length of the struts attached to these nodes that overlap the boundary or both of these values. In this manner, the shape of the structure may be maintained when having nodes along the boundary.

As further shown in FIG. **12**, when the nodes **25-35** are repositioned, the remaining struts connected to the nodes **25-35** may then be lengthened or shortened as required to maintain connectivity between the nodes. In this manner, the outermost nodes and struts may be positioned such that they do not coincide with the boundary by any function of the cell size or geometry. This effect can be seen clearly in FIG. **19**(*c*).

In a variant of this embodiment, the nodes **25-35** may not be moved but instead discarded and replaced by new nodes. Additionally, the struts connected to the nodes **25-35** may be replaced by new struts that are longer or shorter than the original struts to maintain the connectivity between the nodes.

The use of polar or spherical coordinates to define nodes may be preferred to the use of Cartesian coordinates when a surface of a model build structure to be formed is curvate or cylindrical. In this manner, nodes repositioned on a boundary may be positioned at the same angle defining a replaced node but at a different radius from the origin of a polar coordinate system being used to create a model build structure. However, other user-defined coordinates may be used to create conformal structures. In other words, a user-defined node positioning system may be used to form a model build structure having nodes along an outer boundary that fit the contours of the outer boundary of the component being modelled.

FIG. **13** shows various cross sections of a tapered, cylindrical geometry. The gray color represents the solid CAD volume which is bounded by a clear, porous CAD volume.

FIG. **14** further shows the geometry of FIG. **13** subsequent to the generation of a plurality of outer nodes **410** and a plurality of inner nodes **430** along inner and outer boundaries **435**, **445** of the porous CAD volume. Such nodes define the vertices of unit cells **450** which are created by virtually slicing the porous CAD volume according to the unit cell height. This operation produces polar rings that are then populated with volumes that pattern radially around the ring of the part. These volumes define the unit cells for the part.

FIG. **15** shows the population of the unit cells **450** created in the previous stage. The depicted geometry is based on the preferred octahedral cell as described previously herein but could be based on any porous geometry. These porous geometries are then defined by nodes with connecting struts or segments **480**, all of which meet at the defined surface of the porous CAD volume **500**. This effect can be seen clearly in FIG. **19**(*b*).

Creation of beneficial surface properties can be achieved through the movement of the nodes **410** at the outer surface **500** of the porous CAD volume. FIGS. **16** and **17** detail the creation of torque or movement resisting features on the surface of cylindrical components. The nodes **410-427** that lie on the outermost boundary of the porous CAD volume **500** can be manipulated to be repositioned along the surface of the porous CAD volume **500** in either direction to create a deformed unit cell with a preferential direction of movement. Such manipulation involves the changing of the coordinate positions of the nodes. For example, the angular component of at least some of the polar coordinates of the nodes along the boundary may be modified in the same or opposite directions to produce an anti-torque effect. In another example, the height component and in some instances the radius component as well of the nodes along the boundary may be modified in the same or opposite directions to produce an anti-backout effect. In producing either of these effects, the struts may correspondingly be lengthened or shortened as necessary to maintain connectivity with the nodes along the boundary. The amount that any coordinate is changed can be based on any empirical or mathematical function.

A similar modification in the vertical direction is shown in FIG. **18**. In this case the nodes on the outermost boundary of the porous CAD volume **500** are manipulated to be repositioned in the vertical direction to create features that are resistant to the part being extracted after insertion.

In another example, as illustrated in FIG. **21**, surface features can be generated on any part where the surface is made up of connected nodes. Intrinsic surface properties can be created through the movement of nodes away from the surface to positions both inside and outside of the porous CAD volume. The location of the new position of a node **151-160** and corresponding struts **161-170** may be a parameter of the building application such that the repositioned node **151-160** will be at a position selected to satisfy a predetermined theoretical surface roughness along the predefined portion of the outer boundary **200**. The theoretical surface roughness may be defined by a formula for surface roughness, such as any of the ANSI/ASME B46.1-2009 standards for surface roughness R_a, R_s, R_z, or R_q. In addition, the new positions of a group of nodes **151-160** and corresponding struts **161-170** along a predefined portion of the outer boundary **200** may be selected such that the surface roughness of the predefined portion of the outer boundary **200** is a predetermined value. Thus, the positions chosen may be selected at random so long as the aggregate of the positions of the nodes **151-160** and corresponding struts **161-170** satisfy the theoretical surface roughness chosen. For example, if R_t is the parameter, then each of the struts **161-170** and nodes **151-160** along the outer boundary **200** must fall within a set distribution between minimum and maximum heights **275** and **285**, respectively, as shown in FIG. **21**.

FIGS. **23**(*a*) and (*b*) depict the surfaces of flat structures formed using a conventional modeling method and some of the approaches described herein. FIG. **23**(*a*) is a photograph of a coupon formed by selective laser melting of powdered metal prepared in accordance with a method known in the prior art. To produce the coupon, a model build structure was prepared with the upper nodes of the regular, octahedral, porous geometry deliberately intersecting the upper surface boundary of the cuboid porous CAD volume.

FIG. **23**(*b*) is a photograph of another coupon formed using the same selective laser melting process as the coupon in FIG. **23**(*a*). The model build structure used to produce the coupon in FIG. **23**(*b*) used the same lattice structure as the coupon in FIG. **23**(*a*). However, an approach in accordance with those described herein was employed to produce the top surface of the model build structure corresponding to the roughened top surface **200** shown in FIG. **23**B. An algorithm was applied to the nodes at the upper surface of the porous CAD volume. This algorithm required a predetermined surface roughness (to a corresponding R_a, S_a or other standard roughness measure) as described previously. FIG. **23**(*b*) shows the resultant built geometry illustrating the surface roughness obtained.

The features previously described herein can be used on any surface. An example of their use on curved surfaces is shown in FIG. **22**. A porous CAD volume that conforms to a surface **100** is used as the base. An upper bound **300** and lower bound **301** define a region **302** in which the surface nodes **25-35** can be repositioned. As in the example shown in FIGS. **8**(*a*) and **8**(*b*), the amplitude and direction of each movement can be controlled to create any predetermined theoretical surface quality eg roughness or surface marking. This same algorithm has been applied to a curved surface detailed in FIG. **24** where the nodes have been moved by a set amplitude to get a desired roughness value on a curved surface.

Specific use can be made of these different roughening algorithms to produce desired effects, for example surface marking for use in product identification. This can be seen in FIG. **25** which illustrates that it is possible to produce markings that are invisible under normal light, and visible under angular directed light, for example by creating areas of different roughness, which may be sub-flush or proud of the surface. This could also be applied in the form of a 2-D barcode or QR code that may contain proprietary information relating to the specific implant to which the coding has been applied. In this manner, the marking may be readable by hand-held laser scanners or other well-known devices.

Another application of the movement of the nodes along and through the surface is demonstrated in FIG. **26**. These relate to the creation of an irregular appearance at the surface of a regular structure. The nodes that are at the surface can be moved along, out of, into or in any combination of these movements to create a modified surface that has irregular qualities but which is based on a regular structure.

Yet a further method of creating surface roughness is shown in FIG. **28**. Additional struts may be added onto the outer nodes **25-35** as defined in the arrangement shown in FIGS. **12** and **410-427** as defined in the arrangement of FIG. **16**. These additional struts do not connect to another strut. In this manner, these struts may give rise to a resistance to movement in a direction at an angle sufficiently perpendicular to the surface.

As contemplated by an embodiment of this invention, self-retaining features, such as the additional struts **520**, may be used to produce a "VELCRO" type effect in tangible structures formed from a corresponding model build structure. In this manner, the outside surface of one tangible structure having a self-retaining feature may be an inverse representation of the outside surface of a mating tangible structure having a corresponding self-retaining feature. For example, the mating structures may each have additional struts that interlock or engage with one another. In another embodiment, additional struts of one structure may fit into pores or holes on the surface of another structure in a "hook and eye" formation to attach the two structures. Other formations include a barbed geometry with corresponding ends, a hooked geometry with corresponding ends, deformable loops, or variations in the depth of the roughening applied to mating surfaces as described previously herein, to create an interlock between the mating surfaces. In some instances, these types of positive engagement may remove or minimize the need for mechanical fixation devices such as bone screws or other assembly devices.

A flow diagram shown in FIG. **29** details an embodiment of the creation of porous geometries within a Cartesian coordinate defined unit cell. At block **610**, a computer-generated model of a three-dimensional structure is prepared. A bounding box is created by a processor. This bounding box is populated with unit cells **620**.

The spatial interaction of the unit cells with the surface of the porous CAD volume is determined, by a processor, and two pathways are created at a step **630**. The unit cells that do not make contact with the surface are then interrogated to determine their position at a step **640**. Unit cells that lie outside the structure are discarded. Unit cells that are within the porous CAD volume are populated with porous geometries **650**.

The unit cells that cross the surface of the porous CAD volume are populated with porous geometries. The struts of porous geometries can then either be clipped to the surface at a step **670** or clipped to a node at a step **680** as described previously herein. In other words, the struts may be clipped to an inner node, an outer node, or at the boundary of the porous CAD volume. However, this approach may leave the surface rough, uneven, and nonconforming to the original porous CAD volume.

Through steps **690-692**, the nodes at the surface can also be manipulated so that all the surface nodes lie on the outer boundary of the porous CAD volume to create a conformal surface.

A process flow diagram shown in FIG. **30** details an embodiment of the creation of porous geometries within polar or cylindrical coordinate defined unit cells. At a step **710**, a computer-generated model of a three-dimensional structure is prepared or a part is defined using geometric parameters.

This model may then be sliced virtually at a step **720** to produce polar rings that can then be populated with unit cells and nodes in a radial pattern at a step **730**. These unit cells may be populated with porous geometries at a step **740**.

A process flow diagram shown in FIG. **31** details an embodiment the creation of surface features through repositioning of nodes that lie on the boundary of the porous CAD volume. This operation can be performed on any porous geometry that consists of struts which interconnect at nodes along the boundary of the porous CAD volume.

At least one node is selected at a step **810** which can then be perturbed in a variety of ways to generate the desired surface properties. In one embodiment, a node along the boundary can be repositioned along a position vector which is at an angle to the surface direction as shown at steps **830-831**. This process may be used to create surface properties such as surface roughness.

In another embodiment, a node can be moved along a position vector parallel to the surface direction across the surface which can be used to create torque or movement resisting, pullout resisting and surface irregularity properties at steps **840** and **841**.

In yet another embodiment, any combination of the steps **830** and **840** may be used to create surface properties. Nodes can be moved both along and away from the surface to create areas of irregularity, roughness and marking at steps **850** and **851**.

In another example as shown in FIG. **32**, a computer-generated component file is prepared at a block **910**. The component file includes a porous CAD volume with a boundary having at least one predefined portion. At a block **920**, a space that includes the porous CAD volume is populated, by a processor, with unit cells that overlap the predefined portion of the boundary. Such a space may be defined by sets of coordinates, such as Cartesian, polar, or spherical coordinates. At a block **930**, the unit cells are populated with porous geometries. Within the porous geometries may be a plurality of struts. At least one end of the struts may have a node. As further shown at block **930**, at one of the struts overlaps the predefined portion of the boundary. Such a strut has a length, one node outside the porous CAD volume, and one node inside the porous CAD volume. At block **940**, any struts entirely outside the predefined portion of the boundary are removed. In some embodiments, any struts outside the entire boundary are removed. In this manner, a computer-generated model of a three-dimensional structure constructed of porous geometries is prepared. At an optional block **950**, a tangible three-dimensional structure having a shape corresponding to the computer-generated model may be produced. The shape of the three-dimensional structure may be in the form of a geometric lattice structure.

Visualization of all of the above effects under consideration can be achieved by voxelating the sliced output files from bespoke software that is being applied in an additive layer manufacturing machine. Utilizing developed algorithms and the output files, the data may be fed into a commercial software package, e.g., Matlab, and the images produced can be interpreted. FIGS. **2**(*a*) and **2**(*b*) illustrate an initial process operation in contrast to FIGS. **19**, **20** and **26** representing common output images.

The approaches for generating three-dimensional models described herein may be used for building various tangible structures and surfaces, specifically structures and surfaces for medical implants. Although a brief summary follows, many details of the process of melting powdered metal are given in the '421 and '327 Applications. In constructing a tangible structure from a model build structure, a layer of metal powder, in some instances, may be deposited on a substrate. The substrate may be a work platform, a solid base, or a core, with the base or core being provided to possibly be an integral part of the finished product.

The metal powder may be Ti alloys, stainless steel, cobalt chrome alloys, Ta or Nb. In some embodiments, individual layers of metal may be scanned using a directed high energy beam, such as a laser or e-beam system to selectively melt the powder, i.e., melt the powder in predetermined locations. Each layer, or portion of a layer, is scanned to create a plurality of predetermined porous geometries by point exposure to the energised beam. This leads to the production of struts that correspond to the struts described previously herein, as will be described below. Successive layers are deposited onto previous layers and also are scanned. The scanning and depositing of successive layers continues the building process of the predetermined porous geometries and oblique struts are directed to nodes. As disclosed herein, continuing the building process refers not only to a continuation of a porous geometry from a previous layer but also a beginning of a new porous geometry as well as the completion of the current porous geometry.

In a preferred aspect of the present invention, the high energy beam may be adjusted to modify the cross-sectional diameter of various struts. Some of the struts of the porous geometries may overlap struts of other porous geometries as a result of randomization within unit cells, but such struts never lose their identity with respect to their origin. Dimensions of strut diameter and unit cell size may enable the adjusting of the porosity throughout the completed structure. The strut diameter preferably should be nominally two times the diameter of the high energy beam, and each unit cell should have sides with lengths preferably no greater than 2 mm and have an aspect ratio that is limited to a maximum of 1:2 with respect to a maximum height of the unit cell.

In some embodiments, a component structure or sub-structure thereof produced by the approaches herein may be porous and if desired, the pores can be interconnecting to provide an interconnected porosity. In some embodiments, the amount and location of porosity may be predetermined, and preferably lie in the range 50% to 90% as being suitable when used as a bone ingrowth surface, and 20% to 90% as being suitable for polymer interlock surfaces. This also applies to cases where the outer porous section of a medical device is connected to host bone with bone cement or bone type adhesives for example. A base or core of cobalt chrome alloy, titanium or alloy thereof, stainless steel, niobium and tantalum, may be used to build a porous layer of any one of these metals and/or alloys by melting using high energy beam, such as a continuous or pulsed laser beam or an electron beam. Thus, a mixture of desired mixed materials can be employed. The porous layers can be applied to an existing article made from cobalt chrome, titanium or alloy, stainless steel, tantalum or niobium, such as an orthopaedic implant. It is thus intended that the approaches described herein may be exploited to produce commercially saleable implants with bone in-growth structures having porous surfaces with a controllable texture or surface profile. Such an implant may be an acetabular component, a knee tibial or patella implant, a femoral knee or hip implant, or the like. The constructed medical implant may have a porosity and architecture optimised, to create very favourable conditions so that bone in-growth takes place in a physiological environment and the overall outcome favours long-term stability.

The medical implants, as well as other constructed structures, may be provided with an attaching mechanism for anchoring or at least more firmly attaching the medical implant to another element. One such example is an acetabular component being provided with a surface structure which mates with the surface of an augment component.

Because a laser melting process may not require subsequent heat treatment or the temperature at which this heat treatment occurs is lower than any critical phase change in the material, the initial mechanical properties of any base metal to which a porous structure is applied may be preserved.

The equipment used for the manufacture of such a device could be one of many currently available including but not limited to those manufactured by Renishaw, SLM Solutions, Realizer, EOS, Concept Laser, Arcam and the like. The laser or electron beam may also be a custom produced laboratory device.

Although the invention herein has been described with reference to particular embodiments, it is to be understood that these embodiments are merely illustrative of the principles and applications of the present invention. It is therefore to be understood that numerous modifications may be made to the illustrative embodiments and that other arrangements may be devised without departing from the spirit and scope of the present invention as defined by the appended claims.

The invention claimed is:

1. A method of preparing a computer-generated model of a three-dimensional structure constructed of porous geometries, the method comprising: preparing a computer-generated component file including a porous computer-aided design volume having a boundary having at least one predefined portion; populating, by a processor, a space including the porous computer-aided design volume with unit cells overlapping the at least one predefined portion of the boundary; populating, by a processor, the unit cells with porous geometries, the porous geometries having a plurality of struts having opposing ends, each end being connected at a node, the plurality of struts including at least a first strut overlapping the predefined portion of the boundary, the first strut further having a length, a first node outside the porous computer-aided design volume, and a second node inside the porous computer-aided design volume; and removing all struts entirely outside the porous computer-aided design volume, such that each end of the remaining struts remains connected at the node.

2. The method of claim 1, wherein a plurality of struts overlap the predefined portion of the boundary, each of the plurality of struts having a length, a first node outside the predefined portion of the boundary, and a second node inside the predefined portion of the boundary, the method further comprising retaining the full length of the plurality of struts overlapping the predefined portion of the boundary to the first node of each of the plurality of struts.

3. The method of claim 1, wherein the first strut is removed when the first node is further from the boundary than the second node.

4. The method of claim 3, the second node being further attached to at least one adjacent strut inside the porous computer-aided design volume further comprising: moving a closer of the first and the second nodes to the predefined portion of the boundary at a position along the predefined portion of the boundary; and when the first node is the closer node, changing the length of at least the first strut such that the first strut remains connected to the first node, and when the second node is the closer node, changing the length of the at least one adjacent strut such that the at least one adjacent strut remains connected to the second node.

5. The method of claim 4, wherein the closer of the first and the second nodes to the predefined portion of the boundary is moved to a location on the predefined portion of the boundary nearest to the previous location of the moved node.

6. The method of claim 3, further comprising: replacing a closer of the first and the second nodes to the predefined portion of the boundary with a replacement node at a position along the predefined portion of the boundary; and replacing the first strut with a replacement strut having the replacement node at one end and the remaining node of the first and second nodes at the other end thereof.

7. The method of claim 1, wherein a plurality of struts overlap the predefined portion of the boundary, each of the plurality of struts having a length, a first node outside the predefined portion of the boundary, and a second node inside the predefined portion of the boundary, the method further comprising moving at least one of the first and the second nodes of at least one of the plurality of struts overlapping the predefined portion of the boundary- to a position to satisfy a predetermined surface roughness along the predefined portion of the boundary.

8. The method of claim 7, wherein at least one of the first and the second nodes of at least two of the plurality of struts overlapping the predefined portion of the boundary are moved to positions selected at random along the predefined portion of the boundary.

9. A method of preparing a computer-generated model of a three-dimensional structure constructed of porous geometries, the method comprising: preparing a computer-generated component file including a porous computer-aided design volume having a boundary having at least one predefined portion; populating, by a processor, a space including the porous computer-aided design volume with unit cells on or overlapping the at least one predefined portion of the boundary; populating, by a processor, the unit cells with porous geometries, the porous geometries having a plurality of struts having opposing ends, each end being connected at a node at the plurality of struts including at least a first strut intersecting the predefined portion of the boundary, the first strut further having a length and a first node at a first location either (i) on the predefined outer boundary or (ii) outside the porous computer-aided design volume; removing only all struts entirely outside the porous computer-aided design volume such that each end of the remaining struts remains connected at the node; and moving the first node from the first location to a second location.

10. The method of claim 9, wherein the three-dimensional structure is adapted to be placed into a separate structure, the method further comprising moving the first node in a direction not parallel to the first strut to create a resistance to movement of the three-dimensional structure when the three-dimensional structure is placed into the separate structure.

11. The method of claim 9, wherein the three-dimensional structure is adapted to be placed into a separate structure, and wherein a plurality of struts intersect the predefined portion of the boundary, each of the plurality of struts having a length and a first node at a first location either (i) on the predefined outer boundary or (ii) outside the porous computer-aided design volume, the method further comprising: moving the first node of the first strut in a first direction not parallel to the first strut; and moving the first node of at least a second strut of the plurality of struts in a second direction not parallel to the second strut and not in the same direction as the movement of the first node of the first strut to create a resistance to movement of the three-dimensional structure when the three-dimensional structure is placed into the separate structure.

12. The method of claim 9, further comprising forming a strut extending from the first node to: at least one of (i) produce a rougher surface of the three-dimensional structure and (ii) produce interlocking features to enable assembly or engagement with at least one additional three-dimensional porous structure.

13. The method of claim 9, wherein a plurality of struts intersect the predefined portion of the boundary, each of the plurality of struts having a length and a node at a first location either (i) on the predefined outer boundary or (ii) outside the porous computer-aided design volume, the method further comprising: moving the first node of the first strut and at least a second node of the-a second strut in a direction away from the predefined portion of the boundary and either (i) outside the porous computer-aided design volume or (ii) inside the porous computer-aided design volume.

14. The method of claim 13, wherein the first node and the second node form at least portions of an identifying marker visible to the unaided eye.

15. The method of claim 13, wherein the first node and the second node form at least portions of an identifying marker invisible to the unaided eye.

16. A method of producing a three-dimensional structure comprising: preparing a computer-generated model of a three-dimensional structure according to claim 1; depositing a metal powder onto a substrate; scanning a beam to form a first layer of the three-dimensional structure, the three-dimensional structure having a geometric lattice structure constructed of formed porous geometries, the formed porous geometries formed by a plurality of formed struts, each of the plurality of formed struts having a formed node on each end thereof, and an outer surface with at least a predefined portion, wherein a portion of the formed nodes lies on the predefined portion of the outer surface.

17. The method of producing a three-dimensional structure according to claim 16, wherein the beam is either (i) an electron beam or (ii) a laser beam.

18. A tangible computer-readable storage medium on which computer readable instructions of a program are stored, the instructions, when executed by a processor, cause the processor to perform a method of preparing a computer-generated model of a three-dimensional structure constructed of porous geometries, the method comprising: preparing a computer-generated component file including a porous com-

puter-aided design volume having a boundary having at least one predefined portion; populating a space including the porous computer-aided design n volume with unit cells overlapping the at least one predefined portion of the boundary; populating the unit cells with porous geometries, the porous geometries having a plurality of struts having opposing ends, each end being connected at a node, each of the plurality of struts including at least a first strut overlapping the predefined portion of the boundary, the first strut further having a length, a first node outside the porous computer-aided design volume, and a second node inside the porous computer-aided design volume; and removing all struts entirely outside the porous computer-aided design volume such that each end of the remaining struts remains connected at the node.

19. The method of claim **1**, wherein during the removal of all struts entirely outside the porous computer-aided design volume, only struts entirely outside the porous computer-aided design volume are removed.

20. The method of claim **9**, wherein the second location is on the predefined outer boundary.

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